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IN THE SEARCH FOR EXTRATERRESTRIAL LIFE

C. Ponnamperuma

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16. Abstract

The search for extraterrestrial life is closely related to the search for the origin of life on earth. Before the biological evolution there was a chemical evolution which, in its first stage, was close to the origin of matter. All experiments which simulate primitive conditions show that life must have followed the same kind of evolution in an incalculable number of sites. There is therefore a real probability of extraterrestrial life and there is hope of contacting it if there exists a civilization far enough advanced in technology and if a proper wavelength is found.

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IN THE SEARCH FOR EXTRATERRESTRIAL LIFE

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"There exist a race of men and a race of gods, /49*
which both received the breath of life from the same mother.
But a contradictory power keeps them separated so that one
is nothing while the other has made the blazing heavens
its serene citadel for eternity."

Pindar, Sixth Ode to Nemeus

Exobiology has established as its principle objective the search for extraterrestrial life. For the official National Academy of Sciences, "the scientific question which sums up the stakes of exobiology opens up the most exciting perspectives, not only for this century but for the whole naturalist movement which has characterized western thought for the last three hundred years."

The study of galactic, stellar and planetary evolution has led modern astronomy to the conclusion that the phenomenon of life must be generally present in the universe.

The sampling presently attained by telescopes has made possible the calculation that there might be 10^{20} stars, each one of which could ensure the photochemical reactions which are at the origin of plant and animal life. Because of divisions, the accumulations which are formed, and the secondary collisions, we may allow that only one star in a thousand possesses a

* Numbers in the margin indicate pagination in the foreign text.

planetary system. Let us suppose that out of a thousand stars with a planetary system, there is, for just one of them, a planet situated at the ideal distance for protoplasm to find the water and the heat necessary to it -- as is the case twice in our own system -- and is large enough to retain an atmosphere, as is the case of seven planets out of nine, again in our system. Let us finally imagine that the chemical compositions necessary to the appearance of life is found only once in a thousand.

Despite these restrictions, we can, without exaggeration, estimate with Harlow Shapley that the possibilities for the existence of life are not less than one hundred million. For the astronomer Su Shu Huang, who takes into account only the time scales of biological and stellar evolution, zones in which stars and dynamic factors can exist, at least 5% of the stars in the universe could permit the birth of life which could therefore exist in about a hundred billion specimens at a minimum. Harrison Brown has recently utilized the function of illumination to evaluate the number of invisible planetiform objects in the vicinity of the sun, according to their probable chemical composition in relation to that of the principal chains of visible stars. The former could, from their size, have collected about sixty cooled-off stars, more massive than Mars, to link themselves to these stars as a planetary system. Our galaxy might even contain at least a hundred billion of them in which conditions favorable to the development of vital processes might even exist more frequently than we believed until today.

There are three possible approaches in the search for extraterrestrial life. First, we could land men or instruments some place in the universe, which we can attempt, for the time being, only in our own planetary system. Next, we could consider a radio contact with other civilizations which have a technology at least as advanced as ours. Finally, we could follow the experimental route by considering life as an inevitable consequence of the evolution of matter: since the laws of chemistry and physics are universal, the laboratory reconstitution of the road which has led to the appearance of life on earth would solidly support our belief in its existence elsewhere.

Life on Mars

The enigma of life on Mars, the first planet where we are trying to land an instrument or an astronaut, is the favorite of scientists. Some have even suggested the existence of very ingenious beings who, by means of a network of giant canals, are supposed to have collected drainage water. According to the present state of our knowledge, Mars is the one planet whose surface configuration is most like that of the Earth. Gravi- /50
tating in an orbit situated at an average distance of 224 million km from the Sun, with a diameter almost equal to half that of the Earth and with a ten times smaller mass, Mars is inclined at an angle of about 24° in relation to the plane of its orbit, as compared to 23.5° for our own planet.

Their periods of rotation (24 and 37 min), as well as their seasonal and diurnal cycles, are very close. It is generally agreed today that the white polar regions are composed principally of solid carbon dioxide and not solely of water, as people thought. These polar regions seem to follow the rhythm of the seasons, spreading during the winter while diminishing during the summer. In 1969, the Mariner rocket registered temperature on the order of 150°K.

The darkness formerly attributed to masses of water or to areas of vegetation covers about a quarter of the planet, especially along the equatorial zone. The contrast between dark region and bright deserts is still unexplained. The average temperature of Mars has been estimated to be 50° lower than that of Earth, with a maximum of about 30° near the equator for several hours a day during the summer, but that temperature falls the next night in the same places to -70° or -80°C.

When submitted to a spectroscopic analysis by balloons, terrestrial telescopes, rockets and scanned by radio occultation, the atmosphere of Mars shows a total pressure of about 6.5 mbar, which no doubt varies from approximately 3 to 15 mbar on certain areas of its surface according to differences in altitude.

An identical analysis of the Earth has made possible the detection of carbon dioxide, carbon monoxide and water.

The observations made by Mariner 6 and Mariner 7 in the region of the ultraviolet rays have specified the composition of the lower layers of the atmosphere of Mars: carbon dioxide, and of the higher layers: CO_2, a little carbon monoxide and some traces of oxygen.

There is probably about 1% nitrogen. Its humidity is extremely minute, probably quite variable and should be between 15 and 50 μm of water in suspension, as compared to 2,000 for Earth.

The surface of Mars, similar in this to that of the Moon, presents an irregular topography, riddled with craters in certain areas, while other areas do not show a ripple for several square kilometers. From the size and the distribution of the craters, we assume that the presently visible configuration has probably not been modified since the formation of the planet. This presumption is based on a comparison between the respective number of craters on Mars and on the Moon, where, according to the study of the specimens gathered during the Apollo 11 mission, they also had most likely not moved during periods on the order of

$4.6 \cdot 10^9$ years. There would therefore not have been any noticeable erosion, and, as a consequence, no great masses of liquid at rest, particularly because of the low atmospheric pressures.

The prospect of life on Mars therefore looks rather bleak, but we cannot eliminate the possibility.

Numerous authors refer to the history of the Earth to try to describe that of the origins of Mars, especially with regard to the appearance of the first reproductive systems and the adaptative processes by which, once the first biological evolution had begun, a selection of organisms according to their increased resistance to dehydration, low temperature, the influex of ultraviolet rays, etc. took place, since the planet progressively lost much of its atmosphere as well as much of its heat. What most limits life is still the lack of water, a primordial factor in coping with fluctuations of temperature, low atmospheric pressures, lack of oxygen and intense radiation. Future observations, especially those from the next Mariner rocket, will perhaps show some local points of water which could be due to partial reheatings of the glacier layer which is situated, according to some, under the surface.

The physical parameters of Mars, however defective they are in comparison with those of the Earth, nevertheless reflect general conditions which could allow microorganisms to survive, and even to multiply. This has been tested in the laboratory, during experiments in which such conditions had been reproduced. Superior forms of life could thus have developed on Mars before becoming extinct and these forms of life will perhaps present themselves to visitors as many fossilized remainders of a formerly flourishing biosphere.

Contacting Other Worlds

Given the probable distribution of life in the universe, we can reasonably postulate the existence of intelligent beings in quite a few places, a billion in our galaxy according to Professor Carl Sagan of Cornell University. The distance between these civilizations can reach a thousand light years and suggests a dimension which appears, on the human scale, almost insuperable. We may recall that in Paris, at the beginning of the century, Mrs. Gusman left 100,000 francs to the Académie des Sciences to reward the first person to succeed in communicating with another world, but that Mars, considered too easy to reach, was excluded.

Two methods of interstellar communication seem feasible: the irradiation of nuclear particles which transmit information at the speed of light, and electromagnetic radiations.

The nuclear particles contain much more energy than photons, and their quantity of information is close to that of electromagnetic radiation. If one choses the latter method, the ideal wavelength for the transmission of a message still has to be /51 determined. Cocconi and Morrison suggested in 1959 that the best frequency was that of a hydrogen band at 21 cm -- its harmonics and subharmonics included; on that frequency, a search for signals was started. We assume in fact that it will be that wavelength on which the choice of possible intelligent beings would fall. Wavelengths of shorter frequency would be interfered with by radio frequencies.

Earlier, Professor Frank Drake compared this prodigious search for intelligent beings to the desire for meeting a friend in New York without arranging it in advance.

This remark from the director of the Ozma project (named for the princess who reigned in the mythical land of Oz) resembles the situation of the radio astronomer in search of a certain kind of frequency to which each being in the heart of the Milky Way could plug in, a kind of privileged spot known to all, where, as in cities, the chances of meeting are greater than if left to chance.

For the moment, we must give all our attention to the two closest stars, Tau Ceti in the constellation Cetus and Epsilon Eridani in the Eridanus constellation.

At the Green Bank Laboratory, they fixed the telescope on Tau Ceti every morning at 3:00. When it disappeared behind the mountains, the telescope was fixed on Epsilon Eridani, etc. A signal as picked up twice, but always the same. Unfortunately, once the antenna was moved, they couldn't help but notice that the signals came from Earth and not from space, from which, after 2 months of investigation, nothing like that was finally registered with certainty.

Such were the first rather disappointing steps of that attempt at contacting other worlds in the Ozma project. These failures should not discourage us in any way. Long years, more powerful radio telescopes and more sensitive receivers will be needed to envisage any hope for success.

<u>Every Thousand Years</u>

Carl Sagan has suggested that a more advanced civilization than ours could have developed methods for interstellar space flight at speeds in accordance with the principle of relativity. To the extent that, within 60 years of the Wright brothers, we have already landed on the Moon, if we could manage to reach these speeds, we could accomplish in the span of a lifetime immense voyages which would require hundreds of thousands of years without the expansion of time. A physical contact between civilizations with advanced technology could, taking into account their possible distribution, be envisaged practically every thousand years.

A Russian work has recently drawn attention to certain incidents in biblical times which are narrated in the apocryphal book Slavonic Enoch. In it, the author sees the report of an inspection of Earth by extraterrestrial cosmonauts. Other legends have, in their particular context, come to reinforce scientific studies in a remarkable way. One can take as an example the Babylonian story of the foundation of Sumer by the Apkallu, considered to be representatives from a nonhuman society and, no doubt, also extraterrestrial.

Which Evolution?

Today we can approach the problems of space biology in the laboratory. Darwin had postulated a total unity of the terrestrial biosphere. According to him, the most evolved forms of life had developed during an enormously long period from inferior forms whose age should reach, according to fossil analyses, 3 billion years. One day life did start on this planet, and, if one believes the geochemists, it probably happened almost 4 billion years ago. What happened between the birth of the planet and the beginning of life? The physicist Tyndall asked himself this question in 1871 in "Scientific Data for Nonscientists" in the following terms: "Darwin placed a primordial germ at the source of life, and, from this germ, the prodigious variety of organisms which people the Earth is supposed to have sprung up. Even if we admit the merits of such an hypothesis, the imagination could not content itself with it in man's ineluctable and perhaps absurd desire to search beyond that germ for the history of genesis .. to link the present of the planet to its past, to know something about his remotest ancestors ... Does life belong to that which we call matter? Or is it, on the contrary, an independent element which, finding at a certain moment ideal physical conditions for its development, suddenly inserted itself into the heart of the matter?"

However it may be, considering biological evolution leads us logically to study the chemical evolution which preceded it and to understand which materials present in the universe could have given birth to chemical compounds and life structures.

All organisms, from the Colibacillus to the elephant are composed of two basic molecules: a nucleic acid and a protein with complex structure, whose concerted action apparently results in that unique property of matter which we generally call life.

Nucleotides assembled like beads on a rosary consisting of a base, purine or pyrimidine, of a sugar and a phosphate make up the nucleic acid molecule. Twenty amino acids fusing with each other form the protein macromolecule.

A fundamental conclusion is reached from any study of living matter whose unity has recently been exactly determined in biochemistry: all organisms must have some chemical ancestor in common.

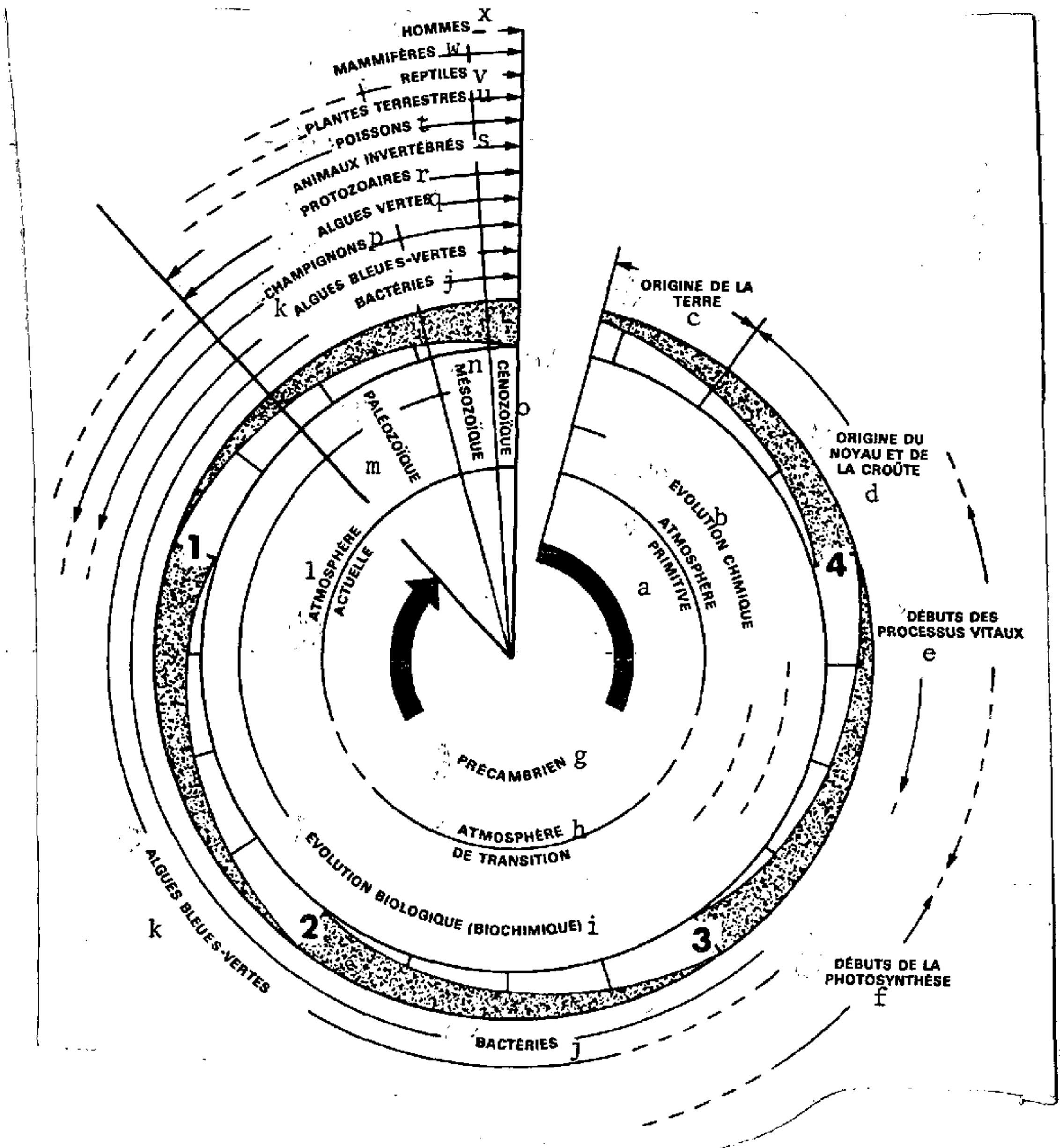
The properly chemical evolution whose first stage no doubt
corresponds to the very origin of matter, probably unfolded by /52
degrees, from inorganic to organic chemistry and, from there, to biochemistry. The elements which are part of the period classification must have appeared during the series of cataclysmic reactions which accompanied the birth of a star. Billions of years later, at the time of the formation of the solar system, the

very reactive elements which characterize living organisms probably existed in combinations with hydrogen, carbon in the form of methane, nitrogen in the form of ammonia, and oxygen in the form of water.

In the same way, there existed rudimentary molecules, ancestors of today's biological polymers, at the time when the planet Earth took shape form the primitive cloud of dust, 4 1/2 billion years ago.

From this scheme, life would still appear as a special property of matter, and it may have arisen on our planet at a particular period of its existence and would have resulted from its earlier development.

The concept of life springing up from the absence of life, or the theory of spontaneous generation, has been well received throughout the centuries. The ancients declared that we should simply rely on our senses: the earthworm issues from mud, maggots from spoiled meat and mice from old tissue. World literature is filled with allusions to this popular belief in spontaneous generation. It is Aristotle in his *Metaphysics* who makes fireflies hatch from the morning dew and mice from the humid earth; this teaching was accepted by a long line of western thinkers who considered him as the final authority in metaphysical and physical matters. It is Vergil, in the *Georgics*, who makes a swarm of bees arise from the carcass of a calf. And then we should recall *Antony and Cleopatra* (Act II, scene vii) /53
in which Lepidus declares to Mark Antony: "Your serpent of Egypt is bred now of your mud by the operation of your sun; so is your crocodile." Newton, Harvey, Descartes, and Van Helmont accept that theory without blinking, and this even includes the English Jesuit John Tuberville Needham, since nothing in Genesis indicates a direct creation of plants and animals by God who had rather commanded the Earth and the waters to bring them forth.



Geological clock. Time in billions of years. After Schopf (1967).

Key:
- a. Primitive atmosphere
- b. Chemical evolution
- c. Origin of the Earth
- d. Origin of core and crust
- e. Beginning of vital processes
- f. Beginning of photosynthesis
- g. Precambrian
- h. Transitional atmosphere
- i. Biological (biochemical) evolution
- j. Microorganisms
- k. Blue-green algae
- l. Present atmosphere
- m. Paleozoic
- n. Mesozoic
- o. Cenozoic
- p. Fungi
- q. Green algae
- r. Protozoa
- s. Invertebrate animals
- t. Fishes
- u. Ground plants
- v. Reptiles
- w. Mammals
- x. Man

An Examination of Life

It was the Russian biochemist Oparin who gave the final impetus to experimental studies on the origin of life. Already in 1924 he emphasized the fact that "the complex combination of manifestations and of characteristic properties of life must have been produced during the evolutionary processes of matter: since the behavior of their molecules is determined by the properties, the disposition and the relations of the atoms which form them, the organic substances see, during the course of their growth and their development, the transformation of their initial characteristics. In that manner, they pass from the simple solution of elementary organic-chemical exchanges to a new chemical-biological arrangement of a colloidal nature."

For his part, in 1928 Haldane was examining the conditions favorable to the emergence of terrestrial life: "The action of an ultraviolet light on a solution of water, CO_2 and ammonia produces a variety of organic substances, including sugars and apparently some of the materials which compose protein. These bodies must have accumulated before the appearance of life until the primitive ocean reached the consistency of a warm watery soup."

We should define the primary matter of an experiment on the origin of life: the initial terrestrial atmosphere. Despite several controversies, the hypothesis of its reducing nature prevails, with its basic argument the enormous quantity of hydrogen which, in its free form, makes up 90% of the known universe. We know that its presence in excess transforms carbon, oxygen and nitrogen into methane, water and ammonia, respectively; these components make up a large part of the atmosphere of Jupiter and Saturn. These great planets have kept the hydrogen in its primitive stage, as revealed by planetary spectroscopy. Meteorites almost as old as the Earth contain metals in their reduced forms, a supplementary argument indirectly supporting the following hypothesis: the molecules which are indispensable to living organisms can be easily produced only in nonoxidizing conditions.

Original Chemistry

On Earth, the first synthesis of organic components happened thanks to four sources of energy. First of all because of the ultraviolet light of the Sun, of which only an infinitesimal fraction could have had a short enough wavelength to dissociate the methane, ammonia and water molecules into products capable in turn of absorbing the energy from the longer wavelengths. After this come, in decreasing order of importance, electrical discharges like lightning and those which can be produced in the corona of close objects, which would have permitted a more effective transfer from the reaction product to the primitive ocean, while occurring near the Earth's surface. Radiation which ionizes by radioactive disintegration of uranium, thorium, and potassium-40 can also have furnished a certain energy, partially materialized in rocks, for example, and partially diffused in the oceans and the atmosphere. Finally, we should not neglect the heat from volcanoes, even though it is not widely distributed and certainly doesn't attain solar efficacy.

Investigations which have used electrical discharges as a source of energy during the last 10 years are of the greatest interest. Miller and Urey have been able to identify four amino acids by subjecting a mixture of methane, ammonia and water to an electric arc.

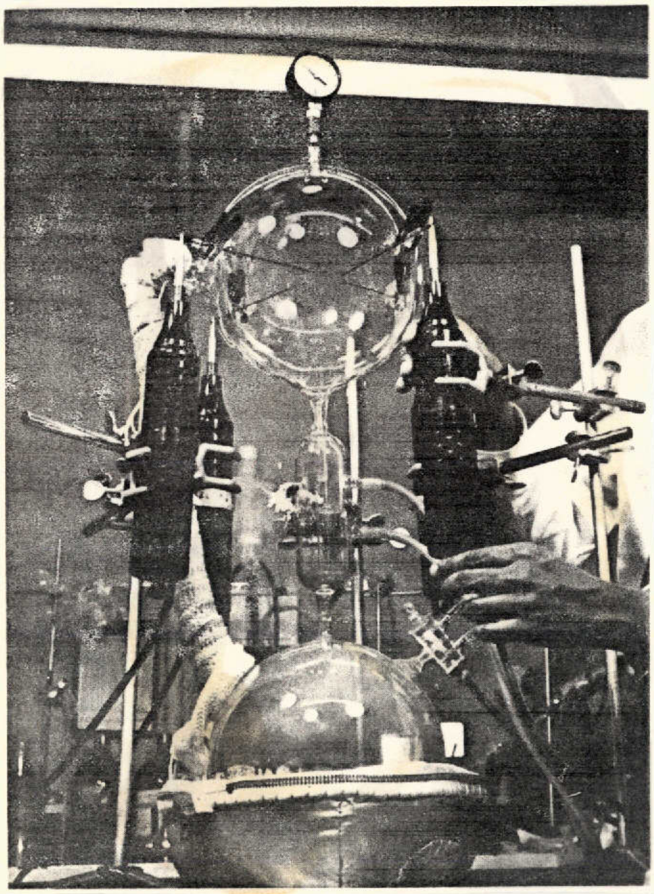
It has since been found that by exposing these element to an electric arc for about 24 hours, more than 95% of the methane was transformed into organic compounds, which were also found as 45% in the aqueous solution, with 18% hydrocyanic acid. This reaction results in cyanamide, an active factor in polymerization, but which here forms the amino acids.

These discoveries lead one to think that a long chemical evolution was not necessary for the first proteins to form. And if we push the speculation further, we can even, if we start at this point, claim that one of these proteins formed at random was a primitive enzyme. If, among such randomly formed polymers, the amino acids had had an activity right for polymerizing in turn, they would probably have produced nucleic acids and proteins.

Whether we proceed by ionizing radiations, electrical discharges or heat, it is hydrocyanic acid which is recovered most often during experiments on the primitive atmosphere.

While in an oxidizing atmosphere this molecules signifies the end of life, it can be considered as the most important link to its origin. The abundance of cyanide or its derivatives in comets underlines the role of hydrocyanic acid in primitive chemistry. In their course to the Sun, they undergo a photodissociation which leaves, in the spectrum of comets, the greatest space to the band of CN, whose presence has recently been reported in intergalactic space. Urey believes that about a hundred comets crashed into the Earth during the first 2 billion years of its existence. From this, the Earth may have kept, by its gravitational and magnetic fields, 10^{12} tons of materials. We now attribute the terrible catastrophe, formerly thought to be due to /54 a meteorite, which shook northern Siberia in 1908, to the collision of a comet.

The steps seem perfectly logical: by subjecting a dilute solution of hydrocyanic acid to ultraviolet light, we obtain, after a chemical modification of its tetramer, an aminomalononitrile, a synthesis of the purines, adenine and guanine, which are found in nucleic acids. Moreover, this corroborates the observation according to which adenine is the largest and only known volatile compound produced by the exposure of methane, ammonia and water to beta particles of a linear accelerator.



Apparatus which can cause electrical dicharges in a primitive atmosphere.

Formaldehyde probably played the essential role during the prebiological formation of ribose and of deoxyribose before their incorporation into ribonucleic acid cells and deoxyribonucleic acid cells. Subjected in solution to ultraviolet light and to ionizing radiation, this compound, which is easily obtainable in atmospheric conditions reproduced in the laboratory, seems to produce all the biological sugars by catalytic condensation.

The action of ultraviolet light on these base and sugar solutions has given rise to nucleosides with the aid of inorganic phosphate, and we will have the nucleotides at 150° and even at 50°.

This kind of reaction is so simple that it could easily have been produced on the prebiological Earth in the dried-up bed of an estuary or on the ocean shore, and clearly shows the beginning of the formation of the chains of dinucleotides, trinucleotides and even tetranucleotides, and that even though a small nucleotide or oligonucleotide is rudimentary compared to a molecule of nucleic acid of a molecular weight of several million.

If we had been able to find an adequate catalysis in the synthesis of the oligonucleotide, its polymerization would have been relatively easy.

Another way of obtaining polymers is by the synthesis of micromolecular condensation: the reaction between two amino acids, for example, gives a peptide; between a base and a sugar, it forms a nucleotides; or, between a nucleoside and a phosphate, it produces a nucleotide. Despite the dehydration of the Earth which would have made them possible, it is difficult to believe that all condensation reactions could have been produced in that way, especially since the withdrawal of a molecule of water, in water, represents a not-to-be-neglected obstacle. Because of enzymes, this kind of reaction is prevalent in living things.

We have thus experimentally shown the possibility of two kinds of prebiological synthesis, aqueous and underhydrated, on the one hand, by performing the synthesis of a polypeptide in a primitive soup formed from methane, ammonia, and water, and, on the other hand, by the phosphorylation of nucleosides in the relative absence of water as in the beginning on Earth when the heat of the Sun, which accelerated evaporation, precipitated at the same time the close contact between nucleosides and phosphates in the organic material deposited in the lagoon and pond beds fringing the first shore.

While inclining slightly towards the hypothesis of the aquatic environment, given the great quantity of liquid, and by reserving the anhydrous condition for microenvironments, we can finally opt for a simultaneous action by the two kinds of mechanisms.

A Return to Origins

Paleontology and geochemistry throw an interesting light on the degree of complexity reached by the molecules in different phases of the chemical evolution. We find its echo in the analysis of sediments which contain their fossilized trace, that is to say, infinitely small quantities of organic compounds. Among them, the hydrocarbons, the most easily detected with certainty, have been the object of an exhaustive study. Numerous criteria have made it possible to establish their biological origins: the presence of pristane and phytane, the abundance of hydrocarbons in a straight chain or the predominance among the latter of odd ones, since hydrocarbons were supposedly formed from a decarboxylation of fatty acids. In schist from the Sudan and in the black silex from Gunflint, 2.7 and 1.9 billion years old, respectively, /55 normal hydrocarbons and isoprenoids, pristane and phytane have been found. Since these last two derive from the phytol chain of the porphyrine molecule, we can say that this photosynthesis no doubt took place during that era.

The search for extraterrestrial organic compounds is linked to the analysis of Precambrian compounds. In meteorites, which are classified among the carbonaceous chondrites and which contain about 5% carbon, certain molecules which can be considered as biological have been recognized, but their extraterrestrial origin nevertheless remains contestable. The meteorite Orgueil which fell in the south of France more than 100 years ago had been making the museum circuit before falling into the hands of chemists. Despite great precautions, the presence of these molecules could be due to a simple contamination.

The first sample of lunar rocks were awaited with a certain feverishness. The presence of any organic molecule would be incontestable proof of a chemical evolution outside the Earth. But, despite 150 mg of carbon per g in the samples, we have not been able to assign any importance whatever to the molecules found in the Sea of Tranquillity and in the Ocean of Storms. But it is not impossible that some organic compounds could, under the surface of the lunar earth, be found sheltered from the ravages of several billion years of ultraviolet radiation and meteorite bombardment.

The study of the origin of life on Earth is but one aspect of a larger problem, that of life in the universe. Given the theoretical considerations on the cosmic distribution of elements, the universality of the laws of chemistry and physics, the analogy between the evolutionary processes of the dust cloud to a protoplanet and of the latter to living matter, like the results of all experiment which simulate primitive conditions, one must admit that life would have followed the same kind of evolution in an incalculable number of sites, and that is could very well be made of carbon, nucleic acids and proteins.

According to the great British biologist Cyril Darlington, the creatures which would populate some far-away planet would in some ways be like us: "Walking on two legs, having two eyes on the same level at the height of 1.5 m to 1.8 m are such considerable advantages that we can certainly envisage the eventuality of the existence of pseudo-men and women which resemble us a little."